Analysis of Transmission Tower under the Effect of Ruptured Wire Loads

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Abstract

Transmission Towers are the main part to bear loads in transmission lines. Without considering seismic loads and wind loads, straight tower (transmission towers in straight line) mainly beard vertical loads; while the angle towers did not only bear vertical loads but also transverse loads. Especially when wires broke, the responses of the different types of towers were also varying under the effect of ruptured wire loads. By the analysis of FEM (Finite Element Methods), it was found that there were much more oblivious displacements, to the direction of ruptured wires, on the straight tower; on the contrary, the responses of angle tower were different. However, in current Tower Design Code, the ruptured wire loads were regarded as static ones without considering the dynamic effects of fragile wire loads.

Keywords

Transmissiontower; Responses Analysis; Ruptured Wire Loads; Straight Tower; Angle Tower

Introduction

Generally speaking, transmission towers are the main parts to bear loads in transmission line system. Normally, the tower bears the gravity of tower and wires, besides, it might receive effects from seismic loads, wind loads, ice loads and thunder loads. Under the condition of operation or installation, wires and landlines, in transmission line system, might break, so tower need bear effects of accidental ruptured wire loads. Although the probability of wires fragile is much smaller, once wires break, outcome would be seriously. For instance, a great many towers have collapsed due to break of wires in Wiscomsin and Indiana of U.S.A in 1975, which led to the whole transmission line system paralysis(Mozer JD 1977); in 1993, about four hundred towers continued collapsing in the transmission line, with length of one hundred and three kilometers, in Nebraska State of America (John D 1977); in 2008, a large number of towers were also destroyed as result of wires fragile, under the effect of ice loads, in the south of China (Fanglin Wang 2008).

Both at home and abroad, there have been a number of researches on transmission tower under the effect of ruptured wire loads, such as, Fleming analyzed imbalance tension in transmission lines by static equation methods, and compiled related computer program(Fleming JF1978); Peyrot studied and estimated formula of the first two peak dynamic

stress in transmission lines under the effect of wires failure(Peyrot AH 1980); Campbell deduced static equation of tower suffering wire ruptured loads, and acquired residual stress and balance position after breaking of wires (David B·Campbell 1970); Mozer deduced partial analysis formula of peak stress, caused by ruptured loads, in light of concise physical model (Mozer J D1981) (Fleming J F 1978); Thomas developed displacement and stress time history programs of insulators and wires in the condition of wires fragile(Thomas M B 1982); Siddiqui compiled static and dynamic equations, with wires breaking instantaneously in transmission lines (Faruq M A Siddiqui1984); Meclure obtained responses of ruptured wire loads condition in 2-d models, adopting ADINA finite element software(McClure G 1987).

Domestic results of researches on transmission tower were mainly on vibration control, due to wind loads and seismic ones, as well as vibration control of wires in transmission lines and so on. However, researches on dynamic responses of transmission tower, under the effects of ruptured wire loads, were much fewer. For example, Zhengchun Xia simulated rigidity of towers by adopting equivalent springs and got dynamic responses of transmission lines(Zhengchun Xia2007); Zhengchun Xia, Li Li and Zhengping Liang acquired responses of transmission tower under the effect of ruptured wire loads, by FEM numerous simulation analysis(Zhengping Liang 2009); Qing Tan, from Logistics Engineering College, provided dynamic responses of transmission tower-line system, under the effect of wires fragile(Qing Tan 2009); in addition,

Guohui Shen, Bingnan Sun, Zenglu Mo and Wenjuan Lou, from Zhejiang University, also studied the impact of tower-line, resulting from ruptured wire loads over and above, and they as well made research on sub impact responses of tower-line, when the broken wires fallen on the ground(Guohui Shen 2009).

Model of Transmission Tower

In this part, the model consists of straight tower-line system and angle tower-line system. Though both straight tower and angle one have the same components, the difference is that angle towers are not in the straight line, but with angle thirty degree. The models of straight tower and angle tower are shown in Fig. 1 and Fig. 2 below.

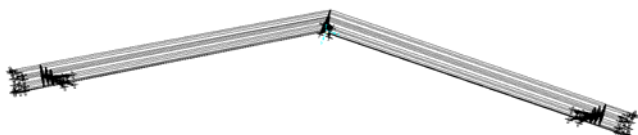FIG. 1 MODEL OF TOWER IN STRAIGHT LINE

FIG. 2 MODEL OF ANGLE TOWER

And the height of tower is 85.9 meters, the width of head tower is 3 meters, and the length of span between two towers is 450 meters.

Wires, on the top, are landlines; and there are four wires on the rest three layers. The brand of wires is LGJ-240/40, and the brand of landlines is JL/LBA99/55, parameters of wires and landlines are shown in table 1.

Both straight tower-line system and angle tower-line system consist of three towers and two spans of wires, and the models of these tower-line systems are established by SAP2000 finite element method program, the model includes 1058 nodes and 2674 rods. Rods are used to simulated angle-steels and wires, but the rods simulating wires only bear tension, are unable to bear press and moments, so the properties of these rods should be magnified. In order to observe dynamic responses of tower, 730, 729 and 77 are selected as calculating joints, while other thirteen rods are as computing rods. Specific position of both specific joints and rods are listed in the Fig. 3 and Fig. 4 below:
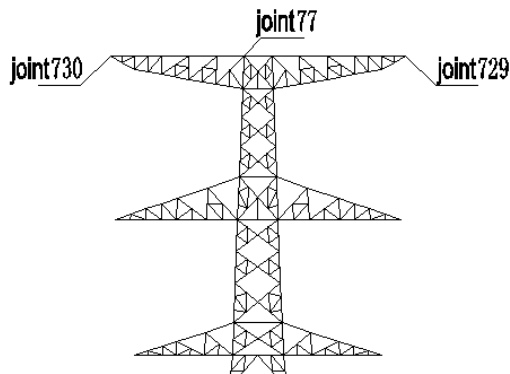

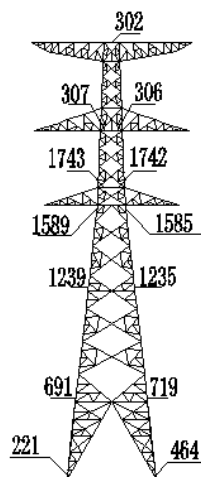
FIG. 3 CALCULATING JOINTS ON THE TOWER

FIG. 4 CALCULATING RODS ON THE TOWER

Analysis of Tower under the Effect of Ruptured Wire Loads

It is assumed that the landlines are intact, only wires break. And the possibility of twelve wires fragile is extremely low, so six wires are assumed to break in the most dangerous condition. When wires break, it is believed that loads on the wires are removed instantaneously (within e-4 second). After wires being fragile, transmission tower vibrates freely under the effect of damp (the damp ratio is 0.02). Just analyzing dynamic responses of tower within ten seconds after wires failure, UX and UY represent displacements of tower, and UX stands for X axial displacement while UY stands for Y axial displacement; impact coefficient η is defined, showing dynamic effects of rods, and $\eta=$ (NU-N0)/N0, NU—ultimate axial stress of rods under the effect of ruptured loads, N0—axial stress of rods under the effect of gravity.

TABLE 1 PARAMETERS OF WIRES AND LANDLINES

grade	Modulus of elasticity/MPa	Diameter/ mm	Area/ mm²	Specific load/N/m. mm²	Operation stress/MPa	Ultimate tension/kN
LGJ-240/40	78.4	18.58	271	34.047	43.09	77.028
JL/LBA99/55	178	13.95	152.8	40.99	103,76	83.48

TABLE 2 AXIAL STRESS AND IMPACT COEFFICIENT OF CALCULATING RODS

element	Axial stress of rods on straight tower			Axial stress of rods on angle tower		
	NUmax/MPa	NUmin/MPa	η	NUmax/MPa	MUmin/MPa	η
302	3.41	-3.58	-0.87	25.35	-27.87	0.99
221	8.56	-8.56	-0.75	65.29	-40.55	-0.15
464	7.66	-7.30	-0.74	66.42	-57.54	1.55
306	11.74	-14.86	-0.13	71.89	-96.63	458
307	20.22	-23.87	0.32	126.95	-155.42	1475
691	13.22	-13.3	-0.64	102.99	-61.80	0.03
719	12.85	-12.25	-0.60	116.23	-98.59	3.64
1235	11.87	-10.9	-0.67	120.93	-109.79	5.5
1239	12.31	-11.04	-0.7	101.52	-76.09	-0.14
1589	18.02	-17.27	0.01	116.20	-111.75	8.74
1585	21.28	-16.69	0.001	149.20	-139.40	0.51
1742	12.22	-16.10	0.37	80.32	-106.26	3.01
1743	9.23	-12.36	-0.34	61.47	-82.21	2.13

Dangerous Condition of One Wire Breaking

According to Fig. 5 and Fig. 7, it is concluded that angle tower has more obvious X axial displacement than straight tower; and in the light of Fig.6 and Fig.8, there is still large Y axial displacement in both straight tower and angle one. In addition, it has been found that both straight tower and angle tower have twist deformation from Fig. 9 and Fig. 10, and the straight tower twists much significantly than angle one. And from the Table 2, it has been observed that there are impact stress appearing in calculating rods, besides the stress of majority of rods on angle tower is larger than that on straight tower.
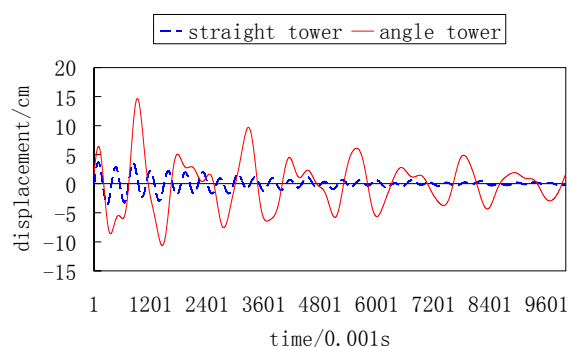

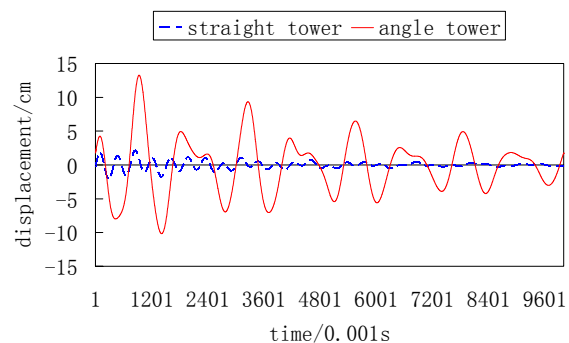FIG. 5 X AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 77

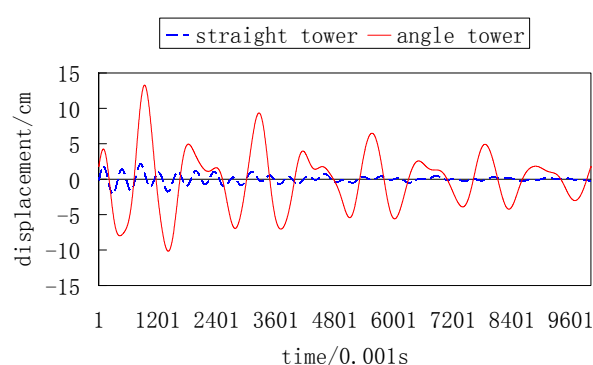FIG. 6 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 77

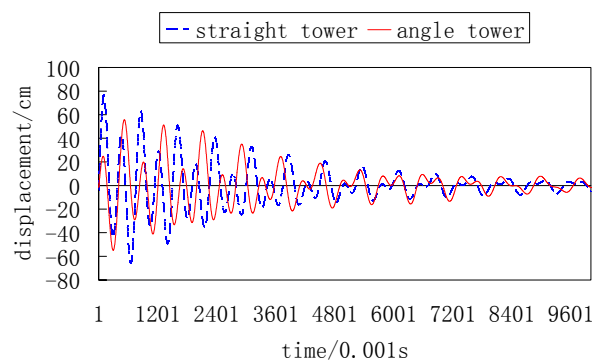FIG. 7 X AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 730

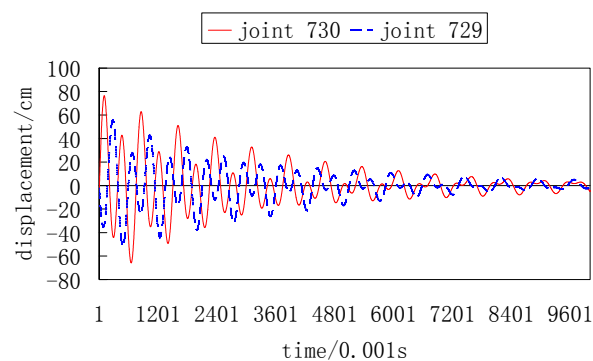FIG. 8 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 730

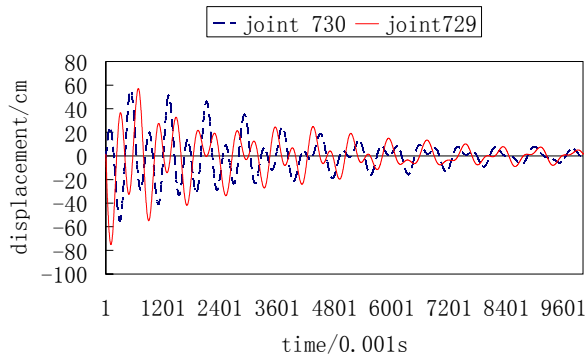FIG. 9 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 729 AND JOINT 730 ON STRAIGHT TOWER

FIG. 10 Y AXIAL PLACEMENT TIME HISTORY DRAWINGS OF
JOINT 729 AND JOINT 730 ON ANGLE TOWER

Dangerous Condition of Six Wires Breakings

Based on analysis above, both straight tower and angle tower under the effect of ruptured wire loads, are deformed greatly. Straight tower deformed greatly along Y axis but a little along X axis from Fig. 11 and Fig. 12; while on the contrary, angle tower didn't deformed intensely not only along Y axis but also X axis according to Fig. 13 to Fig. 14. With the rising number of ruptured wires, these effects will be more obvious. And the peak value of Y axial displacement on straight tower is up to 162.7 cm from Fig. 15, while the maximum value of Y axial displacement of angle tower is up to 187.3 cm from Fig. 14. Additionally, the peak value of X axial displacement on angle tower is up to 76.11 cm while the value of straight is so small that it can be overlooked.

Besides, there are great relative displacements appearing on the both sides of cross arms, which means that there are obvious twisted deformations on both straight tower and angle tower. Over and above, with the increasing number of ruptured wires, distorted deformation on straight tower will be much larger according to Fig. 15; while twisted deformation on angle tower tends to decline even disappear according to Fig. 16.
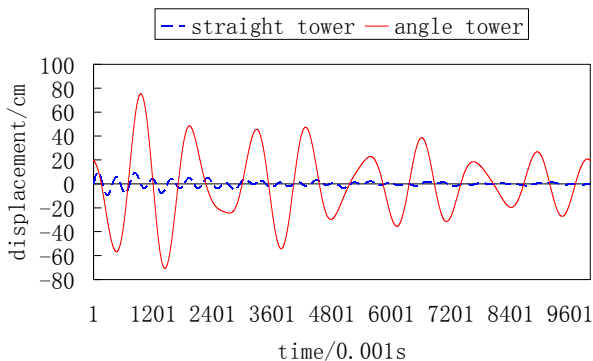

FIG. 11 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS
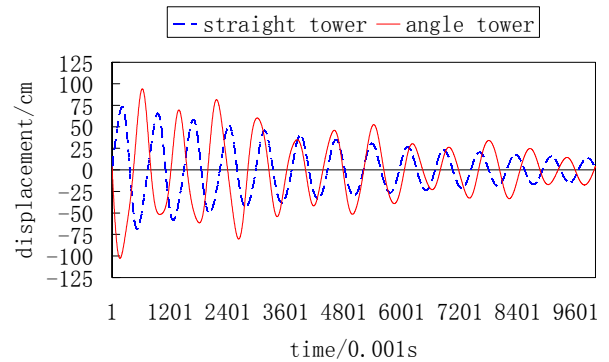OF JOINT 77

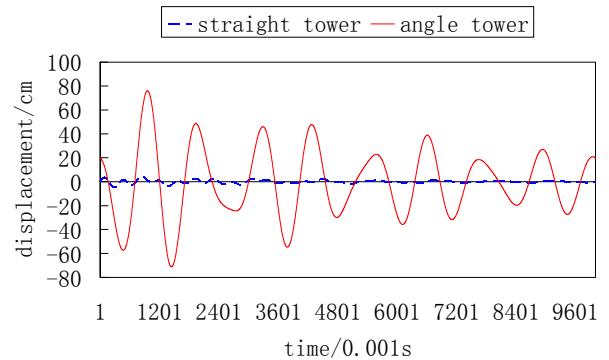FIG. 12 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS
OF JOINT 77

FIG. 13 X AXIAL DISPLACEMENT TIME HISTORY DRAWINGS
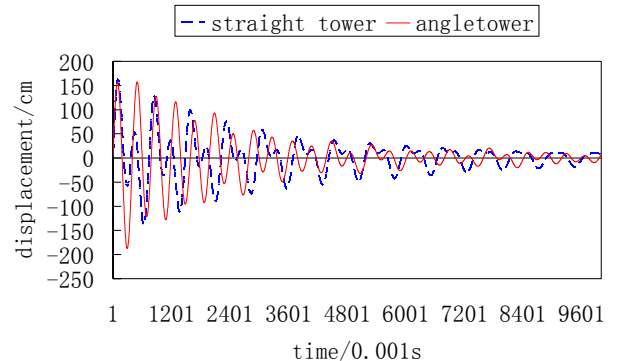OF JOINT 730

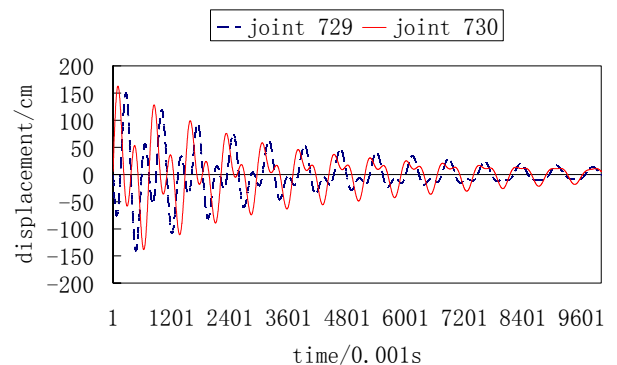FIG. 14 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS
OF JOINT 730

FIG. 15 Y AXIAL TIME HISTORY DRAWINGS OF JOINT 729 AND
JOINT 730 ON STRAIGHT TOWER

TABLE 3 AXIAL STRESS AND IMPACT COEFFICIENT OF SPECIFIC RODS

| element	Axial stress of rods on straight tower			Axial stress of rods on angle tower		
	NUmax/MPa	NUmin/MPa	η	NUmax/MPa	NUmin/MPa	η
302	78.89	-87.95	1.98	71.84	-86.63	4.63
221	151.07	-126.41	2.63	223.76	-136.61	1.86
464	147.63	-143.37	4.2	233.49	-196.25	7.7
306	142.63	-171.95	9.07	82.05	-93.63	443.75
307	261.16	-316.68	16.51	75.16	-87.00	825
691	250.32	-211.53	4.72	360.83	-216.91	2.63
719	268.84	-260.61	7.45	415.29	-346.26	15.31
1235	397.08	-376.87	10.38	491.92	-466.73	26.62
1239	413.87	-378.42	9.36	454.91	-333.76	2.78
1589	317.79	-316.54	17.45	388.06	-379.98	31.25
1585	296.02	-269.19	15.16	428.79	-491.60	4.34
1742	189.11	-224.42	20.22	85.05	-94.21	3.24
1743	137.79	-162.42	8.88	97.74	-102.11	3.98
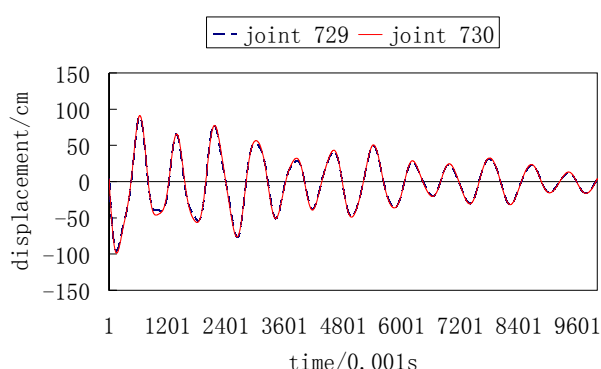
FIG.16 Y AXIAL DISPLACEMENT TIME HISTORY DRAWINGS OF JOINT 729 AND JOINT 730 ON ANGLE TOWER

After wires break, large impact stress will emerge in tower components. And with the rising number of ruptured wires, the peak stress of calculating rods will become larger, as listed in Table 3. Due to the different characteristics of loads of straight tower and angle tower, the impact stress of corresponding calculating rods changes significantly, and this phenomenon also can be explained by impact coefficient η.

Conclusion

(1)Under linear elastic condition, the dynamic responses of transmission tower can be simulated much better by FEM.

(2)After wires breaking, great displacement appears on tower head and cross arms; at the same time, there is also considerable relative displacement emerging in cross arms. The tower may step into geometry nonlinear condition, consequently, it is limited to make analysis by adopting linear elastic theory.

(3)In the light of analysis results, both straight tower and angle tower experience extremely large deformation under the effect of ruptured wire loads; moreover, the responses of angle tower are even more intense than those of straight tower. So it is unreasonable to consider the ruptured wire loads as static one, but this dynamic effects should be taken into account.

REFERENCES

David B, Campbell. "Unbalanced Tensions in Transmission Lines." Journal of the Structural Division Proceeding of American Society of Civil Engineering, 1970, 96 (STl0): 2189—2207.

Fanglin Wang, "the Discussion on the Break of Transmission Tower in South Area of China."Special Structure, 2008(6):14—16(In Chinese).

Fleming J F, AtIlins R S, Mozer J D·A "Program for Longitudinal Load Analysis of Electric Transmission Lines."Computers and Structures, 1978, 9 (3): 237-253.

Faruq M A Siddiqui, John FFleming. "Broken Wire Analysis of Transmission Line Systems." Computer and Structures, 1984, 18 (6): 1077—1085.

Guohui Shen, Zenglu Mo, Bingnan Sun, Wenjuan Lou. "Study on the Impact Effect of Transmission Tower Lines System Due to Sudden break of Wires." Vibration and Impact, 2009:5—8 (In Chinese).

John D.Mozer, Joe C.Pohlman, John F.Fleming"Longitudinal Load Analysis of Transmission Line Systems." IEEE Transactions on Power Apparatus and System, 1977, 96 (5):1657—1664.

Mozer J D,Wood William A, Itribar John A." Broken wim tests oil a Model Transmission Line System." IEEE Transactions on Power Apparatus and System, 1981, 100 (3): 938—947.

Mozer JD.Pohlman Joe C, Fleming, John F. "Longitudinal

Load Analysis of Transmission Line Systems."IEEE Transactions on Power Apparatus and System, 1977, 96 (5): 1657—1665.

McClure G, Tinawi R. "Mathematical Modeling of the transient response of electric transmission lines due to conductor breakage." Computer and Structures, 1987, 26(1/2): 41—56.

Peyrot AH, Kluge R O, Lee J W. "Longitudinal Loads from Broken Conductors and Broken Insulators and Their Effect on Transmission Lines." IEEE Transactions on Power Apparatus and Systems, 1980, 99 (1): 222—234.

Qing TanHua Cheng, Zhonggang Wang, Yanfeng Li, Shifeng Liu. "Dynamic Responses of Transmission Tower Line System under the Effect of Ruptured Wire Loads."Journal of Logistical Engineering University, 2009(5):15—18 (In Chinese).

Thomas M B, Peyrot A H. "Dynamic response of ruptured conductors in transmission lines ." IEEE Transactions on Power Apparatus and System,1982,PAS—101 (9): 3022—3027.

Zhengchun Xia, Li Li. "Dynamic Response of Transmission Tower under the Effect of Wire Fragile Loads on the Lines." Vibration and Impact 2007(3):46—49(In Chinese).

Zhengping Liang, Li Li, Cheng Wang, Zhengchun Xia. "Dynamic Response of Large Span Transmission Tower under the Effect of Fragile Wire Loads on the Lines." Journal of Huazhong University of Science and Technology, 2009(3)3—46 (In Chinese).